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ADMINISTRATIVE INFORMATION

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EXECUTIVE SUMMARY

Three-dimensional (3-D) views of battle spaces generally depict military assets as miniature realistic icons. Little is known about a user's ability to accurately classify and identify realistic icons. We found in a previous study that participants could name a conventional two-dimensional (2-D) military symbol faster than a realistic three-dimensional (3-D) icon. In Experiment 1 of the current work, participants were required to search for tracks represented as flat military symbols or realistic icons displayed in a 2-D top-down view or a 3-D perspective view. Tracks were differentiated by the attributes of identity, affiliation, heading, speed, altitude, and attitude. Tracks imaged as symbols were easier to find than tracks imaged as icons when searching for identity and affiliation in 2-D and 3-D. Icons were easier to find than symbols in 2-D and 3-D when searching for speed. When searching for heading, icons were easier to find in 2-D while symbols were easier to find in 3-D. No differences were found for track altitude or attitude.

Results from Experiment 1 are inconsistent with previous studies that found better performance when searching for track attitude in a 3-D perspective view than a 2-D top-down view. In those experiments, attitude was coded explicitly by the tilt of realistic icons in a 3-D view, while in the 2-D view, attitude was displayed in a digital format in a separate window when the track symbol was selected. The performance advantage of the 3-D perspective view could be attributed to simple coding differences rather than dimensionality of the displayed battle space. In Experiment 2, we investigated this possibility by systematically manipulating the depiction of attitude and altitude by varying display format (2-D versus 3-D), by hooking (versus no hooking), and by coding (digital versus analog). As expected, search with hooking was slower than search without hooking and search with digital coding was slower than search with analog coding. Searching a 2-D view for tracks at given altitudes and attitudes represented as symbols was faster than searching a 3-D view populated with equivalently coded realistic icons.

Participants performed best when tracks were imaged in a 2-D view as symbols enhanced with analog codes. Finding and identifying icons can be difficult in either 2-D or 3-D, because icons for platforms of the same category are similar (all aircraft tend to look alike), which leads to poor discriminability. Moreover, when icons are rendered in 3-D, frame shape depicts platform, heading, and attitude, which leads to ambiguity about each. Frame shape only depicts affiliation for symbols. Icons are beneficial for depicting heading, but only in a 2-D top-down view. The coding of heading by the direction of the icon in 2-D is more conspicuous than the direction leaders on symbols. We recommend:

- Use symbols rather than realistic icons when rapid, accurate platform identification and affiliation are required.

- Improve symbol design to more conspicuously code heading, platform category, and speed.

- Use explicit analog indicators (e.g., drop-lines, posts) for altitude, and attitude regardless of display format or track representation.

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INTRODUCTION

Three-dimensional (3-D) views of battle spaces generally depict military assets as miniature realistic icons. Little is known about a user's ability to accurately classify and identify realistic icons. These displays are thought to be beneficial because they might provide "at a glance" situation awareness. Figure 1 shows a prototype 3-D display for the Area Air Defense Commander (Dennehy, Nesbitt, and Sumey, 1994).

Figure 1. A "3-D" perspective display populated with realistic icons.

In our previous study (Smallman, St. John, Oonk, and Cowen, 2000), participants were presented with icons or symbols one at a time and asked to name them as quickly as possible. We found that standard military symbols (MIL-STD-2525B) were named faster and more accurately than 3-D icons[1]. We believe that the icons were named slower because of the visual similarity of the platforms. For example, cruisers and frigates are so visually similar that they are difficult to differentiate and identify. Abstract symbols can be designed to be as dissimilar as necessary to promote rapid identification.

We seek to replicate this result using a visual search paradigm. There were several experimental design deficiencies in our previous study. First, in our naming experiment, much of the benefit of symbols over icons stemmed from symbols including the first letter of the platform (e.g., 'F' for fighter). We found that non-letter symbols were still named faster than icons, but the effect was much smaller. This result is troubling, because it suggests that the symbol advantage may have simply

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[1] We used MIL-STD-2525B (Department of Defense, 1999) symbols because they differentiate platforms and, hence, we could compare them against icons that inherently differentiate platforms.

reflected priming the verbal response. Would the symbol advantage over icons remain if the participants performed a non-verbal identification task, such as a visual search?

Second, in our previous experiment, the stimuli to be named were presented in isolation on a uniform gray background. This presentation format may have penalized the effectiveness of icons because icons are should be shown in a real-world perspective view. Supporting this argument, Humphrey and Jolicoeur (1993) showed that identification of a foreshortened line drawing of a simple object was improved by presenting the drawing in a realistic context that was consistent with the perspective projection in the drawing. We wanted to determine if symbols were still superior to icons when presented in a real-world context such as a geoplot rendered in 3-D perspective. Visual search of tracks is a more realistic experimental paradigm than naming isolated tracks. We were also interested in determining if display format affects the searching of tracks by attributes (e.g., heading, speed, altitude, and attitude). In the first experiment reported here, we required participants to search for tracks represented as flat military symbols or realistic icons displayed in a 2-D top-down view or a 3-D perspective view. Tracks were differentiated by the attributes of name, affiliation, platform category, heading, speed, altitude, and attitude.

Visual search experiments at other laboratories have reported a marginal advantage for icons over symbols. Florence and Geiselman (1986) conducted visual search for icons versus symbols in 2-D displays and found a small icon advantage. We question their implications because their icons were only shown in 2-D, and their participants were only provided 1 minute to learn the symbols or icons. Participants may have had difficulties identifying symbols because of the short training period.

Baumann, Blanksteen, and Dennehy (1997) found a search advantage for 3-D icons when participants searched for descending aircraft in a 3-D perspective view populated with realistic icons (like the one in figure 1) compared to a 2-D top-down view populated with Naval Tactical Data System (NTDS) symbols[2]. However, attitude information was coded very differently in the two display conditions. Symbols in the 2-D view required hooking to display a digital attitude readout while attitude was coded explicitly by the tilt of realistic icons in a 3-D view. The performance advantage of the 3-D perspective view could be attributed to simple coding differences instead of dimensionality of the displayed battle space. If symbols were redesigned to encode attitude explicitly, performance with symbols should match performance with icons. We also investigated the effect of different coding schemes for altitude and attitude on search times by varying display format (2-D versus 3-D), by hooking (versus no hooking), and by coding (digital versus analog). This investigation allowed us to evaluate the separate effects of symbol and information coding schemes.

[2] NTDS symbols, used on Aegis cruisers, do not show platform or affiliation explicitly.

EXPERIMENT 1

METHOD

Participants

The participants were 32 students from local universities who were paid for their participation. The participants were unfamiliar with military track symbols. The participants were randomly assigned to one of four display condition groups.

Stimuli

There were four display conditions: "3-D + Icons" (a 3-D perspective view with icons), "2-D + Icons" (a 2-D top-down view with icons), "3-D + Symbols" (a 3-D perspective view with symbols) and "2-D + Symbols" (a 2-D top view with symbols). The icons or symbols were overlaid on a 2-D top-down or 3-D perspective scene of a littoral battle space. There was a faint white grid shown on the terrain to accentuate the sense of depth in the perspective view. Figure 2 shows scenes from the four conditions. Each scene contained 48 tracks imaged as all symbols or as all realistic icons. Each track possessed seven attributes (identity name, platform category, affiliation, heading, speed, altitude, and attitude). The track attribute-coding scheme is described below.

Symbology. The tracks for the 2-D and 3-D conditions were rendered either as symbols or icons and were imaged the same as the stimuli in our previous study (Smallman, Schiller, and Cowen, 2000). We used the same set of eight military platforms: four surface/subsurface platforms (carrier, cruiser, submarine and tanker) and four air platforms (bomber, fighter, helicopter and missile). The symbols and icons were of approximately equal size (i.e., the same number of pixels). The symbols were conventional military symbols, drawn according to the specifications of MIL-STD-2525B except for the depiction of altitude and attitude for air tracks. Posts connecting the ground plane to the aircraft coded altitude and attitude. The height of the posts indicated altitude and the direction of the post's arrowhead indicated attitude. Altitude and attitude posts were also added to the icons.

The icons were created from models of the eight platforms taken from *Corel DREAM 3-D* (Corel, 1996). The models were brought into *3-D Studio Max* (Autodesk, 1999) and rendered at eight different headings (N, NE, E, SE, S, SW, W, NW) for each of the three attitudes: level (0°), ascending (15° up), and descending (15° down). For the 3-D environment, the icons were rendered from a camera looking down at a 45° elevation angle and were scaled slightly in size with distance to improve the perception of depth (see Smallman et al., 2000). For the 2-D environment, only level icons were rendered from a camera looking straight down.

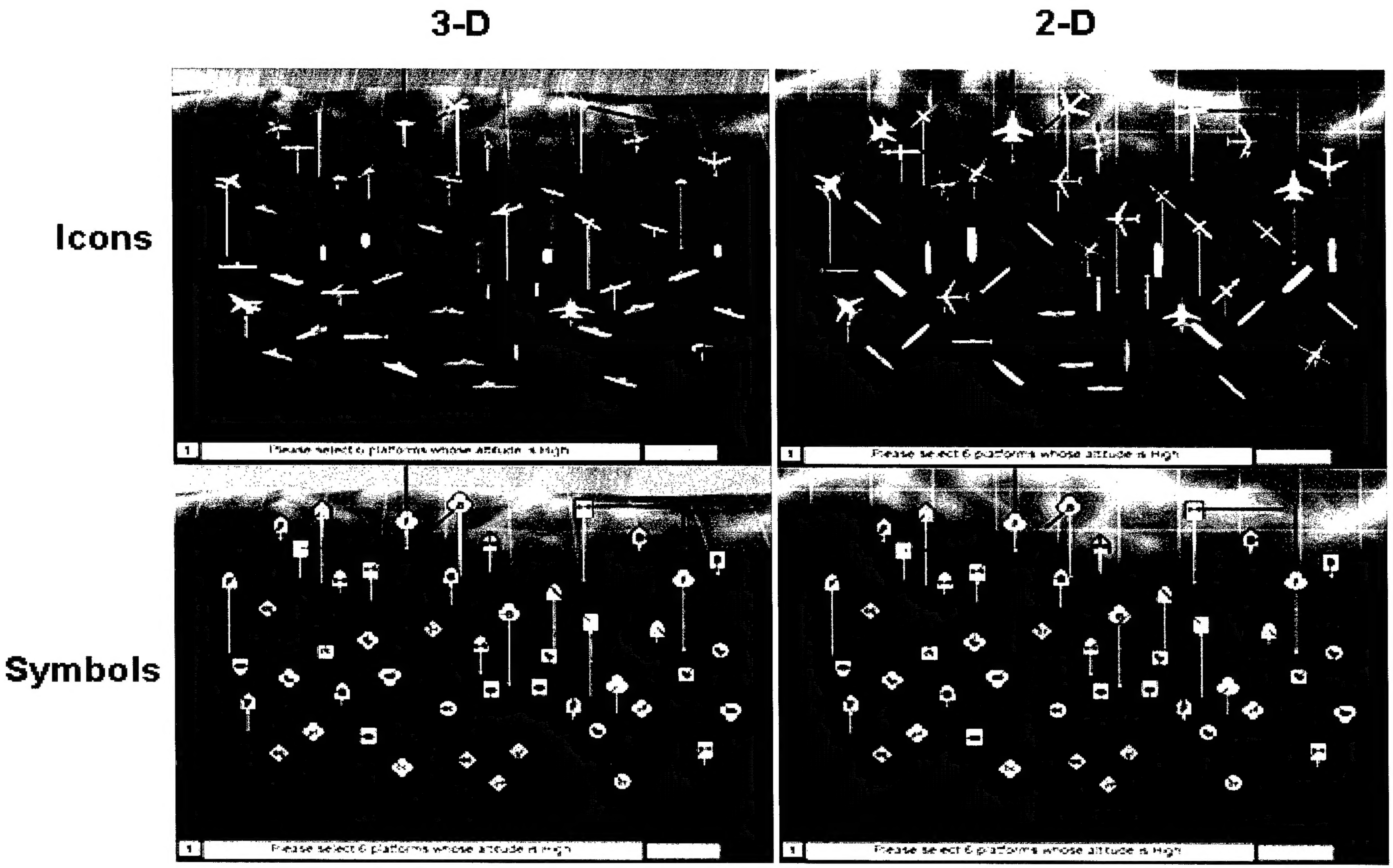
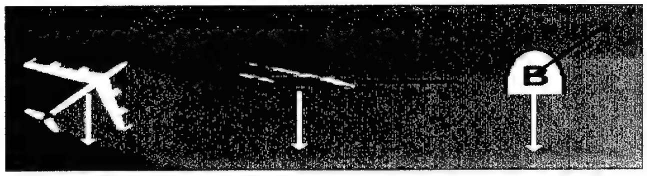


Figure 2. Example of the four display conditions tested in Experiment 1.

Attribute Coding. Table 1 shows the attribute-coding scheme for the symbols and realistic icons.

Table 1. Attribute-coding scheme for symbols and icons in the four display conditions. The example shows a friendly bomber headed NE at medium altitude descending.



	Attribute	Icon in 2-D	Icon in 3-D	Symbol in 2-D & 3-D
	Platform identity	Shape	Shape	Symbol
Identity	Platform category	Shape	Shape	Frame border
	Affiliation	Color	Color	Color + frame shape
	Heading	Leader + shape direction	Leader + shape direction	Leader direction
	Speed	Leader length	Leader length	Leader length
Spatial	Altitude	Post height	Post height	Post height
	Attitude	Post arrow	Post arrow + shape tilt	Post arrow

The coding scheme of table 1 worked as follows:

1. **Platform Identity.** The platform identity for symbols was represented by the letter or logo shape inside the frame of the symbol (e.g., the B in the example represents a bomber). For icons, platform identity was represented by the shape of the icon (e.g., the icon is a miniature representation of a bomber). Icons in 2-D are shown from a top-down view. Icons in 3-D are shown from a perspective view.

2. **Platform Category..** The platform category for symbols was represented by the frame around the symbol letter or logo (e.g., the frame without a bottom on the bomber letter indicates an air track; sea tracks have a complete box or circular frames). For 2-D and 3-D, the icons platform category was represented by the shape of the icon (e.g., the bomber icon is an aircraft and, therefore, an air track).

3. **Affiliation.** The affiliation is the color-indicated affiliation for icons and symbols. There were four different affiliations: blue for friendly, red for hostile, green for neutral, and yellow for unknown. For symbols only, the shape of the frame also indicated affiliation (e.g., rounded frames indicated friendly tracks).

4. **Heading.** Black lines called leaders indicated heading for icons and symbols. There were eight headings equally spaced around the clock (N, NE, E, SE, S, SW, W, and NW). For icons only, heading was also indicated by the direction of the icon (e.g., pointing the icon in the direction that the track was going).

5. **Speed.** The length of the heading leader indicated the speed of air tracks for icons and symbols. The longer the leader, the faster the air track. For air tracks, leaders were short, medium, or long. For sea tracks, all leaders were short.

6. **Altitude.** Altitude of the air tracks for icons and symbols was represented by the height of white vertical lines called posts (i.e., drop-lines) connecting the ground plane to the aircraft: The longer the post, the greater the altitude. Posts were short, medium, or long. Sea tracks possessed zero altitude and, hence, possessed no post. Altitude posts generally have been used only in 3-D (to unambiguously specify location), but are also used here to show altitude in 2-D.

7. **Attitude.** Attitude of air tracks for icons and symbols was indicated by the direction of an arrow on either end of the altitude post. Attitude was either ascending, level, or descending. An upward pointing arrow is an ascending track, a downward pointing arrow is a descending track, and no arrow is a track in level flight. For icons only displayed 3-D, the tilt of the icon in 3-D space indicated attitude (i.e., the downward tilt of the bomber icon indicates descent).

Design

Each participant was randomly assigned to one of the four conditions (n = 8). Each participant served in six search blocks. Each block tested one attribute (platform identity, affiliation, heading, speed, altitude, and attitude). The order of the six attribute blocks was counterbalanced. There were 20 trials in each block. The order of presentation of the trials within a block was random. It took about 1 hour to complete all six blocks.

Procedure

At the beginning of the experiment, the participants were provided a description of the coding scheme for the symbols or icons for their search condition. Then, they were given 5 minutes to study a poster that explained the attribute coding scheme. It included a full set of the symbols or icons for their condition. They were then tested on their ability to identify the correct track attributes using an online questionnaire of 48 questions. The questionnaire was administered until the participant scored more than 90% correct.

At the beginning of each block, participants were told to search for one track attribute (e.g., "Find six fighters," "Find six friendly tracks"). Participants were instructed to search through the display as quickly as possible and to use the mouse to select six tracks that met the criterion for that trial. Participant latency and selections were recorded for each trial. Feedback to a correct response included (1) a white circle around the track, (2) an auditory tone, and (3) a checkmark to one of six boxes at the bottom of the screen to indicate how many correct tracks remained to be selected. Feedback to an incorrect response (one possessing the wrong track attribute) was a low-frequency auditory warning tone. When the six correct tracks had been selected, the participant advanced to the next trial until all the trials were completed.

RESULTS

Figure 3 shows the mean search times to select six correct tracks by track attribute for each display condition. Figure 4 shows the mean accuracies in percent error (i.e., percent incorrect). An error was defined as selecting a track with different track attributes than those specified. Search times and errors were analyzed for each of the six track attributes (platform name, affiliation, heading, speed, altitude, and attitude) and are discussed below.

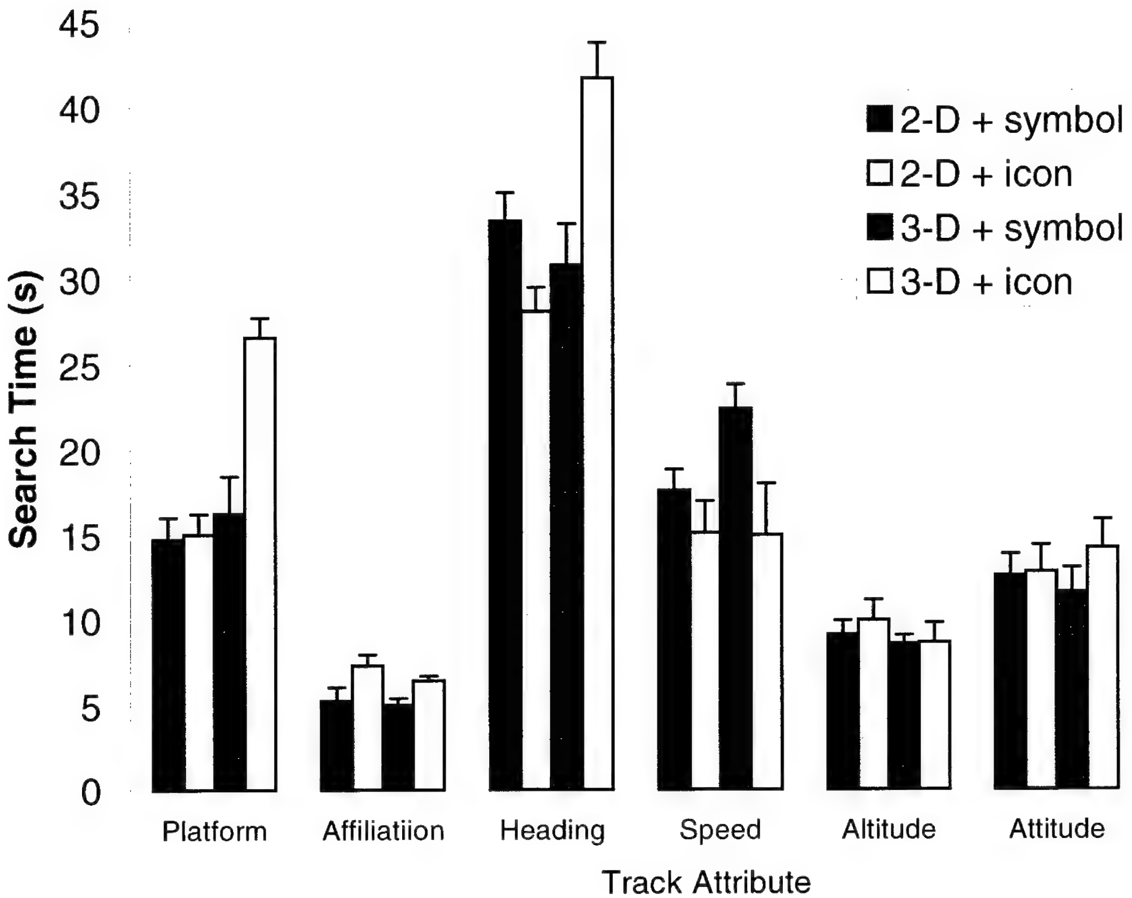


Figure 3. Mean search times by track attributes for each display condition.

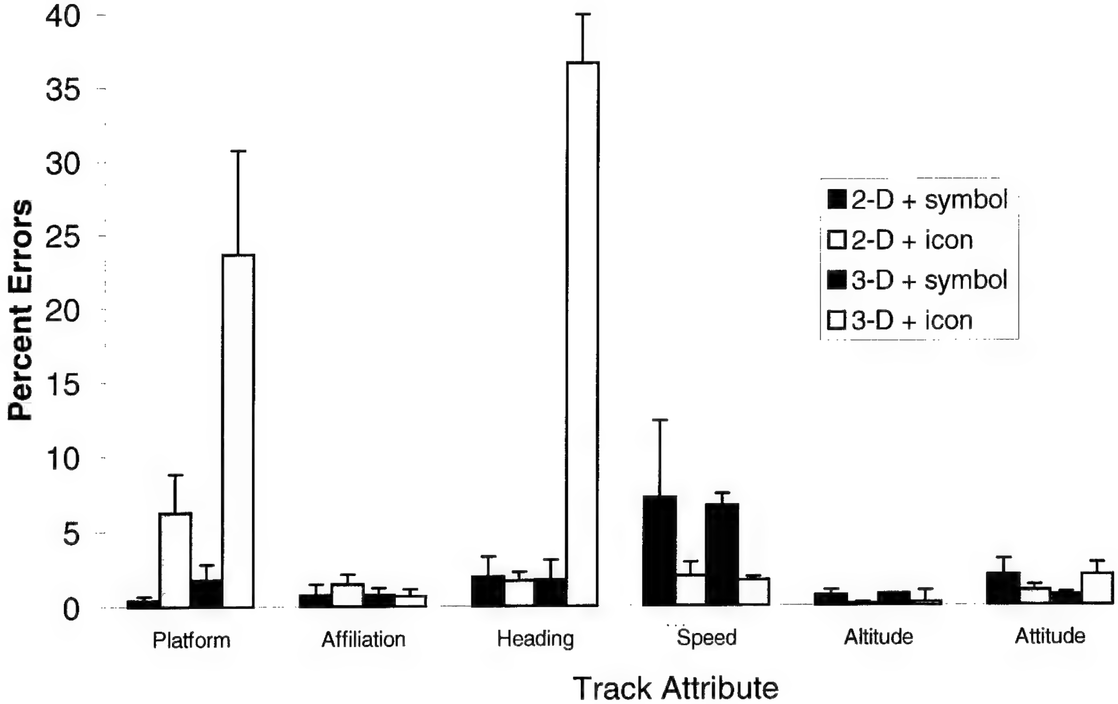


Figure 4. Mean percent errors by track attributes for each display condition.

Platform Identity

Tracks were identified about 5.3 seconds faster when imaged as symbols than when imaged as icons ($F(1, 24) = 12.4$, $p < .01$). Tracks were identified about 6.5 seconds faster in 2-D than in 3-D ($F(1, 24) = 18.9$, $p < .001$). Icons were identified particularly slowly in 3-D ($F(1, 24) = 11.1$, $p < .01$). Main effects can be entirely attributed to slow search times for the "3-D + icons" condition. The other three conditions were not statistically different from each other.

Tracks were identified about 13 times less accurately when imaged as icons than when imaged as symbols ($F(1, 24) = 13.45$, $p < .01$). More errors were made in 3-D than in 2-D ($F(1, 24) = 6.2$, $p < .05$). Icons were particularly error-prone in 3-D ($F(1, 24) = 4.6$, $p < .05$). The error rate for a 3-D environment populated with icons was over 20%.

Affiliation

Searching for affiliation was faster for symbols than for icons ($F(1, 24) = 9.9$, $p < .05$). No significant differences or interactions were found between 2-D or 3-D. There were no main effects or interactions for accuracy. For icons and symbols, color indicated affiliation; however, symbols are uniform patches of color, whereas icons have a non-uniform color fill because of shading and fine details. Participants may have been able to search the symbols faster because the human color vision system is more sensitive to coarse spatial details than to fine ones (Boynton, 1979). Symbols of a given affiliation may have also been easier to find because the shape of the symbol frame redundantly codes for affiliation.

Heading

Searching for heading was about 5.5 seconds faster in 2-D than in 3-D ($F(1, 24) = 8.23$, $p < .01$). However, icons were about 10.9 seconds slower than symbols in 3-D, but about 5.3 seconds faster than symbols in 2-D ($F(1, 24) = 17.8$, $p < .001$).

Searching for heading was much less accurate with icons ($F(1, 24) = 79.5$, $p < .0001$) and in 3-D ($F(1, 24) = 79.7$, $p < .0001$). These effects were entirely caused by numerous errors in the "3-D + icons" condition ($F(1,24) = 81.8$, $p < .0001$). The error rate for this condition was over 36%. The error rates for the other three conditions were not statistically different from each other, averaging about 1.8% errors. The primary difficulty with icons in 3-D is that the depictions of heading and attitude are confounded. For example, in a 3-D perspective view, aircraft heading northeast in level flight will appear to be ascending aircraft traveling east. Moreover, perception of attitude in 3-D is difficult for aircraft icons heading north or south because points on their narrow frames are on the same line-of-site.

Speed

Searching for tracks at a given speed was about 4.9 seconds faster with icons than symbols ($F(1, 24) = 6.1$, $p < .05$). No significant differences or interactions were found between 2-D or 3-D. There were no main effects or interactions for accuracy. Icons may be easier to rapidly classify into platform category than symbols because of the gross visual similarity in their shapes. Perhaps participants were able find air tracks, which vary in speed, faster and avoid searching through task-irrelevant surface tracks, which were all assigned the same speed.

Altitude and Attitude

No significant differences or interactions were found for altitude. Searching for tracks of a given altitude was equally fast in 2-D and 3-D, and equally as fast as symbols or icons. This finding is surprising because altitude is displayed more intuitively in 3-D.

No significant differences or interactions were found for attitude. Searching for tracks of a given attitude was equally fast in 2-D or 3-D, and equally as fast as symbols or icons. Although icon attitude and heading are imaged together in 3-D, track attitude by itself was easy to find because icon attitude was double-coded using arrows on the altitude posts.

DISCUSSION

Generally, tracks imaged as symbols were easier to find than tracks imaged as icons. This replicates our previous results found with our naming paradigm (Smallman, St. John, Oonk, and Cowen, 2000). Despite their realism, icons are difficult to identify. There are two likely reasons. First, there is a high similarity among certain icons. In the naming study, errors were most common among the most similar icons. It is difficult to see how to avoid this problem (when imaging icons) because the actual platforms are quite visually similar. Adding labels to the icons presumably would help, but this addition may add clutter to the display and transform the icons into hybrid symbols. The second reason that icon performance was poor is that icon shape is a completely overburdened visual attribute. Frame shape simultaneously depicts platform, heading, and attitude, which lead to ambiguity about each. This ambiguity inevitably leads to slower search performance and a higher error rate. Frame shape only depicts affiliation for symbols.

EXPERIMENT 2

In Experiment 1, searching for tracks at a given speed was faster with icons than symbols. One explanation (as mentioned above) was that icons were easier to classify into general platform categories than symbols because of gross visual shape similarity. This characteristic of icons, which may have hindered platform identification, may have helped participants with classification. Air tracks would be found faster if searching through task-irrelevant surface tracks could be minimized. We conducted a second experiment to investigate this possibility. We evaluated icons and symbols for category search. If this explanation is true, then participants should be able to find six air tracks, for example, faster when using icons than when using symbols.

We also found in Experiment 1 that searching for tracks at a given altitude and attitude was equally fast with either symbols or icons in 2-D or 3-D. This finding contradicts Baumann, Blanksteen, and Dennehy (1997). Baumann et al. found that locating descending aircraft was faster with icons in 3-D than with symbols in 2-D. How can these results be reconciled? Baumann et al. displayed their realistic icons in a 3-D view where attitude was coded explicitly by tilt. In comparison, attitude was displayed in a digital format in a separate window when the track symbol was selected (i.e., hooked) in the 2-D view. So, three display variables were changing at once: Display format (icons in 3-D versus symbols in 2-D), coding (analog versus digital), and access to the information (explicit versus hooking). Figure 5[3] shows the variable breakdowns, which yields eight different ways of coding of altitude and attitude.

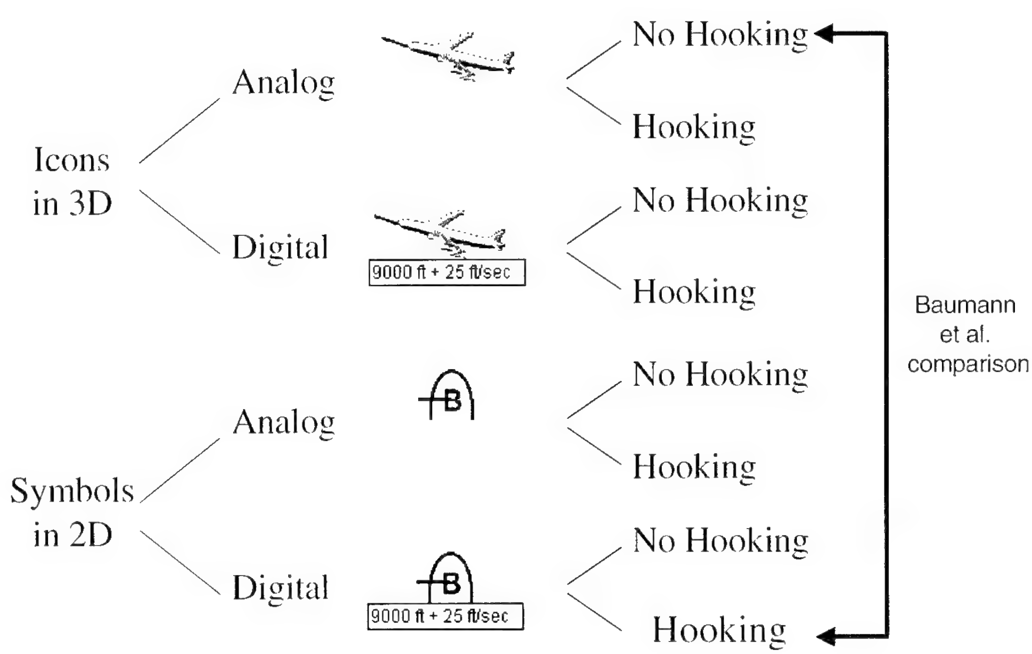


Figure 5. Different ways of coding altitude and attitude.

[3] There are other subtle interface details that figure 5 does not capture. For example, hooked information can be displayed on a second screen or in a pop-up text box, and analog coding for altitude can be represented by the length of an altitude post or by the distance between an icon and its drop-shadow. However, these details are all secondary to the primary distinctions that are drawn in figure 5.

Referencing figure 5, Baumann et al. compared icons in the 3-D/analog/no hooking configuration to symbols in the 2-D/digital/hooking configuration (see orange comparison arrow) and found that the icons in the 3-D display were searched faster than the symbols in the 2-D display. In Experiment 1, we found that searching for icons in a 3-D /analog/no hooking configuration was as fast as searching for symbols in the 2-D/analog/no hooking configuration. Our null result from Experiment 1 suggests that it may not be the 2-D versus 3-D display format that was responsible for Baumann et al.'s difference. The performance advantage of the 3-D perspective view could be attributed to simple coding differences instead of dimensionality of the displayed battle space. In the Experiment 2, we investigated this possibility by systematically manipulating the depiction of attitude and altitude by varying display format (2-D versus 3-D), by coding (digital versus analog), and by hooking (versus no hooking).

METHOD

Participants

Thirty-two different students from local universities were recruited. These participants were paid for their participation and were unfamiliar with military track symbols.

Stimuli

Eight display conditions were tested in the experiment, one for each of the coding schemes shown in figure 5. In the no-hooking conditions, the third dimension information (e.g., altitude, attitude) shown under the symbols was continuously visible, whereas in the hooking conditions, that information was only revealed when participants moved the cursor over the body of an air track symbol. Analog coding was the same as that used in Experiment 1, namely, white altitude posts whose length was proportional to altitude, and white attitude arrows for descent and ascent. Digital coding consisted of a text box that contained altitude and attitude data. There were three altitude levels and three attitude positions: High altitude was shown as "27,000 ft," medium altitude as "9,000 ft," and low altitude as "3,000 ft." Ascending tracks were shown as "+25 ft/sec," level tracks were shown as "+0 ft/sec," and descending tracks were "-25 ft/sec." The same categorical scales (high, medium, and low) for altitude and attitude were used across all coding conditions. Stimuli were in all other ways identical to those used in Experiment 1.

Design and Procedure

The 32 participants were randomly assigned to one of four groups (icon/analog, icon/digital, symbol/analog, symbol/digital). Each group (n = 8) searched tracks with and without hooking. Each participant served in five search blocks. In the first block, participants were required to search for six tracks of a given platform category (air versus sea). The remaining four blocks tested two track attributes (altitude and attitude) by two types of access (hooking or no hooking). The order of these four blocks was counterbalanced across participants. There were 20 trials in each block. The presentation order of the trials within a block was random. It took about 1 hour to complete all five blocks. The experimental procedure was the same as described in Experiment 1.

RESULTS AND DISCUSSION

The mean search times to select six correct tracks by attribute (e.g., platform category, altitude, attitude) by condition were calculated. No significant differences or interactions were found for categorization. Searching for tracks of a given platform category was about the same when imaged as symbols in 2-D (about 8 seconds) or imaged as icons in 3-D (about 10 seconds). This finding provides no support for the idea that it is easier to discriminate air tracks from sea tracks among icons because of their gross shape. If anything, the data suggested that symbols were trending towards faster classification. We had speculated that the reason that search for tracks at a given speed in Experiment 1 was better for icons was because of enhanced classification for icons. However, we found that searching for air tracks was as fast with symbols as with icons. Even though they realistically depict platform category (e.g., air, sea), icons may hamper platform categorization because they are shown at a variety of headings on the screen. At some headings, icons of one platform type may be less discriminable from icons of another platform type. Recall that poor discriminability is one of the main reasons that icons were poor for platform identification (Smallman et al., 2000). We will need to investigate other possibilities to explain why search for track speed is superior with icons.

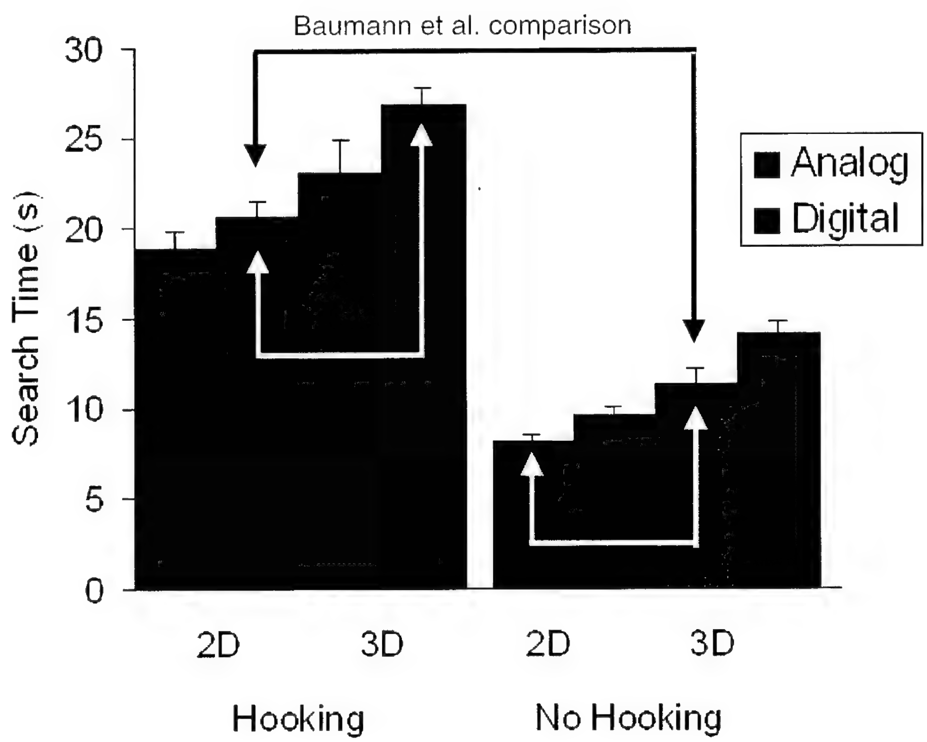


Figure 6. Mean search times across the two attributes (altitude, attitude) for the four conditions. The Baumann et al. comparison across display formats is shown as orange arrows. The comparisons they should have made to equivalent-coding schemes for their two conditions are shown in green.

Figure 6 shows mean search time averaged across altitude and attitude by display format (2-D versus 3-D), by coding (digital versus analog), and by information access (hooking versus no hooking). Searching for digital codes was about 2.4 seconds slower than searching for analog codes ($F(1, 28) = 6.5$, $p < .05$). Search with hooking was about 11.6 seconds slower than search without hooking ($F(1, 28) = 179.0$, $p < .0001$).

The comparison suggested by Baumann et al. is designated with the orange line and arrows in figure 6. Our findings replicate the Baumann et al. result. Searching for tracks with a 2-D/digital/hooking configuration was slower than searching for tracks with a 3-D/analog/no-hooking configuration. However, when coding and information access is analyzed by display format (the green lines and arrows shown on figure 6), searching for symbols in 2-D is about 4.4 seconds faster than searching for icons in 3-D ($F(1,28) = 22.0$, $p < .0001$). The reason Baumann et al. found an advantage for icons in 3-D was simply because hooking was not required to get altitude or attitude information. The performance advantage of the 3-D perspective view could be attributed to obvious coding differences instead of the dimensionality of the displayed battle space.

GENERAL DISCUSSION

The primary purpose of these experiments was to determine whether the advantage for symbols over icons that we had previously found in our platform identification task extended to the more realistic paradigm of visual search. Symbols were easier to find than icons, although the results were somewhat different for tracks imaged in a 2-D top-down view versus a 3-D perspective view. Participants performed best when tracks were imaged in a 2-D view as symbols enhanced with analog codes. In 3-D, tracks imaged as symbols were found about twice as fast and had 13 times fewer errors when compared to searches with tracks imaged as icons. In 2-D, the time to find tracks was the about the same for symbols and icons, but participants still made 13 times more errors with icons than with symbols. We have argued that the essential problem of using icons to represent tracks in Navy operational displays is low discriminability (Smallman et al., 2000). Unfortunately, similar-looking, real-world objects map to similar-looking icons, which results in 3-D realistic displays being populated with various similar-looking ship icons and similar-looking aircraft icons. This condition makes it difficult to search for specific platforms. Symbols, on the other hand, can be engineered for arbitrarily high discriminability because they are not required to depict tracks pictorially. Poor icon discriminability accounts for the much higher error rate with icons than with symbols, but it does not account for why icons are so much worse in 3-D than in 2-D. It is possible that realistic coding with icons imposes an impossibly high burden on the visual aspect of shape. Shape codes for two attributes with icons in 2-D: platform identity and heading. Shape codes for three attributes with the icons in 3-D: platform identity, heading, and attitude. In comparison, shape[4] codes only for one attribute (affiliation) for the symbols in either 2-D or 3-D. Triple coding of attributes for icons in 3-D may have led to ambiguity and uncertainty about a platform's identity and might account for the observed difference in performance between 2-D and 3-D icons.

Although symbols were better than icons for finding tracks of specific platforms or a given affiliation, icons were easier to find in some cases. Finding tracks at a given heading was better with icons than for symbols in 2-D. In 3-D, this pattern was reversed. The heading advantage for icons in 2-D can be attributed to the unambiguous coding of icon direction over that of a leader, replicating our previous finding that the headings of 2-D icons were remembered better than that of 2-D symbols (Smallman, Schiller & Mitchell, 1999). Two major problems exist when trying to understand the heading of a track imaged from icons in 3-D. First, the triple coding of shape for heading, attitude, and platform, mentioned above, often confound judgments of heading and attitude. Second, and more importantly, there is a discrepancy between the projected heading of the leader for 3-D icons in a perspective view and the conventional cardinal directions associated with flat-panel displays (e.g., top of the screen is north), and this discrepancy is exaggerated when the attitude of air tracks are not level. For example, although the 3-D icon of the bomber in table 1 is going northeast, its leader projects to a conventional eastward direction on the display. Participants can accurately reconstruct indicated heading only if they know the three dimensional direction of the leader. Even though participants were aware of this discrepancy, they had considerable difficulty mapping icon direction to track heading. This difficulty was a problem for 3-D displays only in the "3-D + Icons" condition, where heading leaders were rendered in perspective view (in the "3-D + Symbols" condition, the leaders were in conventional cardinal directions). The extremely poor performance found for identifying the heading of icons in 3-D highlights the difficulty of correctly interpreting depicted spatial relations in a perspective view (St. John, Cowen, Smallman, and Oonk, 2000).

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[4] We are referring here to the shape that surrounds the symbol, not to shape of the symbol's interior (e.g., a letter, a logo).

Speed was imaged as leader length for symbols and icons. However, searching for tracks at a given speed were faster with icons than symbols. There are two possible explanations. First, icons may be easier to rapidly classify into platform category than symbols because of the gross visual similarity in their shapes. Participants found air tracks faster and avoided searching through task-irrelevant surface tracks. However, we found no differences between symbols and icons in searching for platform category in the Experiment 2, and there were no differences between symbols and icons in naming the platform category in our previous track identification experiments (Smallman et al., 2000). The other possibility as to why icons at given speed were easier to find is that the speed leader was the only black line associated with an icon. In contrast, there were several black lines surrounding a symbol in addition to the speed leader.

Our work with symbols and icons shows a mixed pattern of results. Tracks are easier to find and identify when imaged as symbols except on the attributes of speed, heading, and category. This fact suggests that a hybrid symbol that combined the best attributes of both might be useful. To this end, we created a hybrid—'Symbicon' (cross of SYMBols and ICONS) symbology—combining the discriminable platform information of military symbols with the salient platform classification and heading information of realistic icons. Symbicons combine the uniform color fill for affiliation and the discriminable symbolic code for platform identity from MIL-STD 2525B symbols (figure 7). They use an outline frame from a realistic icon for rapid appreciation of platform category (e.g., air, sea) and this frame is rotated to depict heading realistically and conspicuously. Preliminary findings using a naming paradigm suggest that 'Symbicons' hold some promise as a useful symbology (Smallman, Oonk, St. John, and Cowen, 2001). Future work will extend these findings to visual search of tracks.

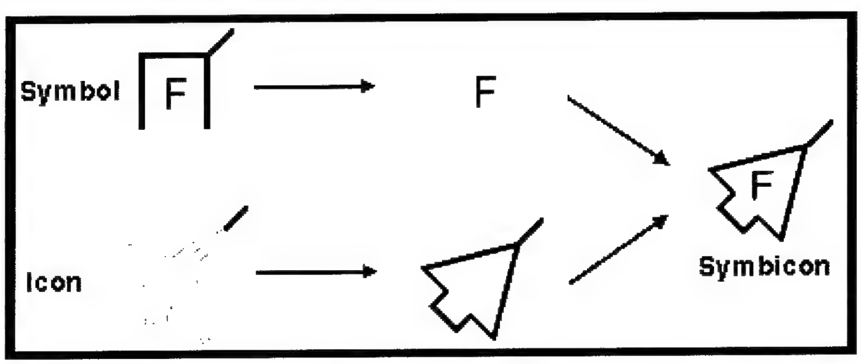

Figure 7. A Symbicon for a neutral fighter is created by combining the interior of a conventional MIL-STD-2525B symbol with a discriminable, shaped outline of a realistic icon.

In conclusion, it is important to understand why other researchers have consistently found a performance advantage for tracks imaged as icons in a 3-D perspective view over tracks imaged as symbols in a 2-D top-down view. Display designers are motivated to use icons imaged in a perspective view because they intuitively depict tracks in a 3-D space. We found that the placement of tracks in the 3-D perspective view was less important to rapid and accurate search of tracks than continuous analogical coding (e.g., leaders, altitude posts) of track attributes. Interestingly enough, this analogical code can also be applied to symbols in 2-D displays to obtain the same high level of performance. In our study of situational awareness for tracks imaged as icons or symbols in 2-D or 3-D (Smallman, Schiller, and Mitchell, 1999), participants recalled tracks imaged as icons in 3-D better for only those attributes that required hooking the symbols in 2-D, such as altitude and attitude. The 3-D display was superior because of continuous analogical augmentations to the display that were introduced to minimize the ambiguity and distortion caused by foreshortening in the perspective view. An important implication here is that those same enhancements can be added to symbols in 2-D displays to realize equal or better user performance.

RECOMMENDATIONS

- Use symbols rather than realistic icons when rapid, accurate platform identification and affiliation are required.

- Improve symbol design to more conspicuously code heading, platform category, and speed.

- Use explicit analog indicators (e.g., drop-lines, posts) for altitude and attitude, regardless of display format or track representation.

REFERENCES

Autodesk. 1999. *3D Studio Max, Version 3.1*. San Francisco, CA.

Baumann, J. D., S. I. Blanksteen, and M. Dennehy. 1997. "Recognition of Descending Aircraft in a Perspective Naval Combat Display," *The Journal of Virtual Environments*. URL: http://www.hitl.washington.edu/scivw/JOVE/Articles/mdjbsb.html

Boynton, R. M. 1979. *Human Color Vision*. Holt-Rinehart-Winston, New York, NY.

Corel Corporation. 1996. *Corel DREAM 3-D, CorelDraw 7*. Ottawa, Ontario, Canada.

Dennehy, M. T., D. W. Nesbitt, and R. A. Sumey. 1994. "Real-Time Three-Dimensional Graphics Display for Antiair Warfare Command and Control." *Johns Hopkins APL Technical Report*, vol. 15, no. 2, pp. 110–119.

Department of Defense. 1999. *Department of Defense Interface Standard: Common Warfighting Symbology*. MIL-STD-2525B. DISA/JIEO/CFS, Reston, VA.

Ditchburn, R. W. 1973. *Eye-Movements and Visual Perception*. Clarendon Press, Oxford, England.

Florence, D. and R. E. Geiselman. 1986. "Human Performance Evaluation of Alternative Graphic Display Symbologies," *Perceptual and Motor Skills,* vol. 63, 399–406.

Humphrey, K. and P. Jolicoeur. 1993. "An Examination of the Effects of Axis Foreshortening, Monocular Depth Cues, and Visual Field on Object Identification," *Quarterly Journal of Experimental Psychology*, vol. 46A, pp. 137–159.

Smallman, H. S., E. Schiller, and C. A. Mitchell. 1999. "Designing a Display for the Area Air Defense Commander that Promotes Rapid Situation Awareness: The Role of 3-D Perspective Views and Realistic Track Symbols." Technical Report 1803 (August). Space and Naval Warfare Systems Center, San Diego, CA.

Smallman, H. S., M. St. John, H. M. Oonk, and M. B. Cowen. 2000. "Track Recognition Using Two-Dimensional Symbols or Three-Dimensional Realistic Icons." Technical Report 1818 (March). Space and Naval Warfare Systems Center, San Diego, CA.

Smallman, H. S., E. Schiller, and M. B. Cowen. 2000. "Track Location Enhancements for Perspective View Displays." Technical Report 1847 (December), Space and Naval Warfare Systems Center, San Diego, CA.

Smallman, H. S., H. M. Oonk, M. St. John, and M. B. Cowen. 2001. "Symbicons: Advanced Symbology for Two-Dimensional and Three-Dimensional Displays." Technical Report 1850 (February), Space and Naval Warfare Systems Center, San Diego, CA.

St. John, M., M. B. Cowen, H. S. Smallman, and H. M. Oonk. 2000. "The Use of 2-D and 3-D Displays for Shape Understanding versus Relative Position Tasks," *Human Factors*, in press.

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14. ABSTRACT
The primary purpose of the two experiments discussed in this report was to determine whether the advantage for symbols over icons that we had previously found in our platform identification task extended to the more realistic paradigm of visual search. In Experiment 1, participants were required to search for tracks represented as flat military symbols or realistic icons displayed in a 2-D top-down view or a 3-D perspective view. Tracks were differentiated by the attributes of identity, affiliation, heading, speed, altitude, and attitude. Tracks imaged as symbols were easier to find than tracks imaged as icons when searching for platform identity and affiliation in 2-D and 3-D. Icons were easier to find than symbols in 2-D and 3-D when searching for speed. When searching for heading, icons were easier to find in 2-D while symbols were easier to find in 3-D. No differences were found for track altitude or attitude. Results from Experiment 1 are consistent with previous studies that found better performance when searching for tracks in a 3-D perspective view than in a 2-D top-down view. The performance advantage of the 3-D perspective view could be attributed to simple coding differences rather than dimensionality of the displayed battle. In Experiment 2, we investigated this possibility by systematically manipulating the depiction of attitude and altitude by varying display format (2-D versus 3-D), by hooking (versus no hooking), and by coding (digital versus analog). Searching a 2-D view for tracks at given altitudes and attitudes represented as symbols was found to be faster than searching a 3-D view populated with equivalently coded realistic icons.

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